Past and Future of CG J1720-67.8: Constraints from Observations and Models

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Summary. We discuss the evolution of the peculiar, nearby (z = 0.045), compact galaxy group CG J1720-67.8, by interpreting a large amount of observational information on the basis of our recent results from spectrophotometric evolutionary synthesis models and new N-body/SPH simulations. The group, that is composed of two spiral galaxies with a mass ratio approximately 4:1 and an S0 galaxy in a particularly compact configuration, is undergoing an active pre-merging phase. Several tidal features are signposts of the complex dynamics of the system. We suggest that the observed structure of the tidal features can be explained only if all three galaxies are involved in a strong interaction process.

Key words: Galaxies: Interactions; Galaxies: Evolution

1 Introduction

Several catalogues of compact galaxy groups (CGs) have been compiled during the last 20 years (e.g. V. Eke, this volume). Many studies have been/are devoted to understand the nature of CGs and their evolution from both an observational and a theoretical point of view (see e.g. the contributions by J. Hibbard, G. Mamon, E. Pompei, this volume). Nevertheless, we do not have yet a clear understanding of how groups evolve and what the product of their evolution is. The study of individual groups in differing evolutionary phases might be useful in this respect, in particular for rarely observed phases, like the pre-merging state represented by extremely compact systems. This is the main motivation of our detailed studies of such a compact system, CG J1720-67.8. In fact, this group gives us the rare opportunity to gather information on the evolutionary stage that precedes the coalescence and provides us with an indication of the processes that might be at play at higher redshifts. In the last few years we collected a large amount of observational information on this system to disentangle its evolutionary history. The application of evolutionary synthesis models allowed us to date the latest bursts of star formation, that are related to the most recent galaxy encounters. In the following we summarize some of the most significant results concerning this system, and discuss its evolution on the basis of the comparison – presented here for the first time – with N-body/hydrodynamical simulations.

2 A very evolved galaxy group

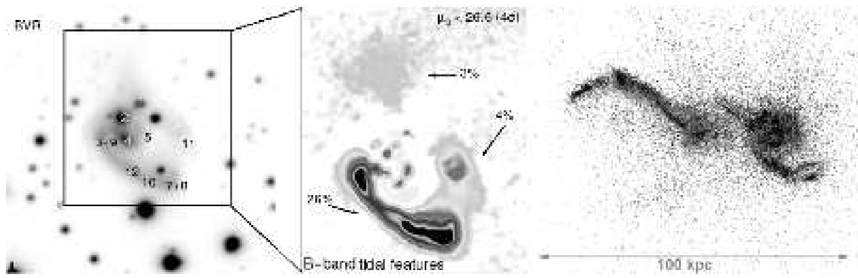

Fig. 1. *Left.* Composite BVR image of CG J1720-67.8. The galaxies and tidal dwarf candidates are labeled. *Middle.* Zoom on the tidal features on the B image after subtraction of the stars and bi-dimensional galaxy models. *Right.* A timestep of the simulation of a prograde encounter between two unequal mass galaxies. The stellar component is plotted in grey and the gaseous component in black (see Sect. 3).

The group CG J1720-67.8 [5, 6], composed of two spiral galaxies (G1 and G4), one S0 galaxy (G2), and a number of tidal dwarf galaxy candidates in a very compact configuration (Fig. 1), appears to be next to the final merging [7]. All components show significant star formation activity. In fact the group has a total (uncorrected) Hα luminosity of 3.7×10^{41} ergs s^{-1} and the total star formation rate derived from the 20 cm radio continuum emission – which is largely unaffected by extinction – is 18 M$_\odot$ yr^{-1}. The prominent tidal features, which account for about one third of the optical luminosity and of the Hα emission of the group, indicate that the galaxies have recently undergone violent interactions. The age of the most prominent tidal tail, based on its projected length and on the kinematics of G4, is estimated to be approximately 200 Myr. This is indicative of the age of the latest strong interaction event.

The velocity field of the group (Fig. 3) obtained from the Hα emission line gives evidence of its complex kinematics. The kinematic center is offset from the center of G4 by about 5 kpc. Galaxies G1 and G4, and the bridge of ionized gas between them have similar systemic radial velocities. Radial velocities gradually increase along the tidal tail from south to north, with a strong gradient in the northern part, near G4 and G2. There is no visible sign of return of tidal material to the parent galaxy. The deficiency of neutral hydrogen in compact groups has been suggested as an indicator of their evolutionary state [9]. The lack of detected neutral hydrogen in CG J1720-67.8, which gives an upper limit to the HI content of 2.3×10^9 M$_\odot$, would suggest that the group is HI-deficient, if compared with the total B luminosity [7]. However, in this case the B-band luminosity is particularly enhanced due to the star formation activity, hence it leads to an overestimate of the expected

neutral hydrogen content of the group. The small size of the galaxies (diameters of ≈ 8 and 14 kpc for G1 and G4), following [2], suggest an expected HI mass $\leq 2 \times 10^9$ $M_\odot$, comparable to our estimated upper limit. The diameters of these strongly interacting galaxies are ill-defined, however, the whole galaxy group with its tidal features, has an optical size comparable to that of our Galaxy, so it is expected to have a similar content of neutral gas. As a consequence, in this case the available upper limit to the HI mass is not sufficient to establish whether the group is HI-deficient or not.

2.1 Results from evolutionary synthesis models

The application of chemically-consistent spectrophotometric evolutionary synthesis models to the three main galaxies of CG J1720-67.8 provided us with information about the age and strength of the latest interaction-induced bursts of star formation [8]. According to the best-fit models, the two spiral galaxies underwent a strong burst of star formation $40 - 180$ Myr ago. An older burst of star formation in the S0 galaxy accompanied either a merger event or an interaction with the companions, ≤ 1 Gyr ago. The total (stars + gas) masses of the galaxies implied by the best-fit models are $3.4 - 7 \times 10^{10}$ $M_\odot$ (depending on the considered model) for G2, $4 - 6 \times 10^9$ $M_\odot$ for G1, and 2×10^{10} $M_\odot$ for G4. Therefore, the total stellar plus gaseous mass of the galaxies involved, without taking into account the material in the tidal tail(s), is $\geq 6 \times 10^{10}$ $M_\odot$. The visible mass of the final group remnant is expected to be on the order 10^{11} $M_\odot$.

3 Clues from hydrodynamical simulations

Observations alone are not sufficient to establish the interaction history of the group, although they give important indications. Extensive numerical simulations are required for this purpose. Here we present a first exploration of the possible evolutionary paths that could explain the observed galaxy configuration, on the basis of combined N-body/SPH simulations. For the modelling we used GADGET-2 [4]. For general assumptions and technical details of the simulations we refer the reader to [3] and references therein. Since the two spiral galaxies G1 and G4 have similar systemic velocities and appear to be connected by a bridge of ionized gas, we first compared the observations with an encounter between two unequal mass disks. The best-fit evolutionary synthesis models imply for these two galaxies a mass ratio $\approx$ 1:3 or 1:4, hence a 1:3 mass ratio was adopted in the simulations. The properties of the simulated galaxies are similar to those listed in table 1 of [3]. Both fast prograde encounters and retrograde encounters between the two disks produce a knotty tidal tail departing from the more massive galaxy, but also a relatively prominent counter-tail departing from the less massive galaxy (see

e.g., the timestep shown in Fig 1). The latter is not observed in CG J1720-67.8. This points to a non-negligible role of the S0 galaxy in the interaction. The presence of the third galaxy could suppress the formation of the counter-tail in the smaller spiral. To test this hypothesis, we introduced the S0 galaxy in our simulation. The formation of the S0 galaxy was simulated through an equal mass disk merger. After 1 Gyr a massive disk approaches the S0 and starts a burst of star formation accompanied by galactic winds (Fig. 2, left). The encounter of this spiral with the merger remnant produces a knotty tidal arm and a bridge of stars and gas toward the S0 (Fig. 2, top-right). Another 15 Myr later, in turn, the less massive disk undergoes an encounter with the S0, is strongly distorted by it, without producing any significant tidal tail (Fig. 2, bottom-right), and starts an induced burst of star formation. Some residual star formation activity is still present at the center of the S0. Although this simulation thus not reproduce the galaxy configuration of CG J1720-67.8, it shows several features similar to the observed ones concerning the morphological distortions, the tidal tails, and the induced star formation. Also the velocity field, projected along a hypothetical line-of-sight, has some similarities with the observed one, as shown in Fig. 3.

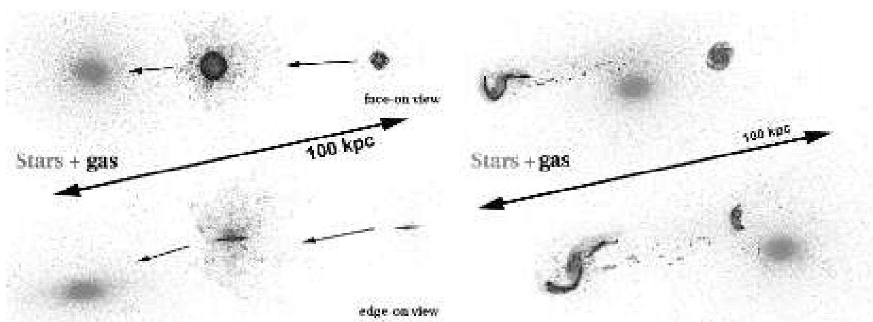

Fig. 2. *Left.* N-body/SPH simulation of the encounter between two disks and an early-type galaxy. At this time-step the larger spiral has started the interaction. *Right.* Subsequent timesteps of the simulation after the encounter of the S0 with the larger spiral (top) and with the smaller spiral (bottom).

4 Conclusions

We found several observational evidences that CG J1720-67.8 is in a late pre-merging phase. The evolutionary stage of the group is similar to that of HCG 31, which is claimed to have started its merging process [1]. According to evolutionary synthesis models the latest interaction episode for the two spiral galaxies took place $<$ 200 Myr ago. Another interaction or merger event appears to have involved the S0 galaxy less than 1 Gyr ago. Our first comparisons with N-body/hydrodynamical simulations indicate that the observed tidal features cannot be simply the result of the interaction between

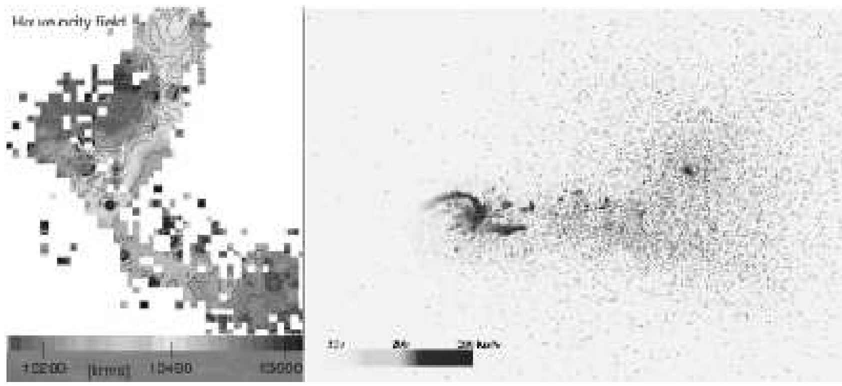

Fig. 3. *Left.* Isovelocity contours overlaid to the velocity field of the gaseous component (from [7]). *Right.* Projected radial velocity distribution of the gas in the N-body/SPH simulation at the last timestep shown in Fig. 2.

the two spiral galaxies. Therefore, we suggest that all three galaxies have been involved in the latest interaction. The extreme compactness and low radial velocity dispersion suggest that the group coalescence will be fast. A simulation in which an S0 galaxy is formed through an equal mass merger and about 1 Gyr later undergoes an encounter with both spiral galaxies produces results that approach the observed properties of the group. The properties of CG J1720-67.8 suggest that sufficiently gas-rich groups might undergo a particularly active star-forming phase before final coalescence.

Acknowledgments. ST is grateful to R. Giovanelli for useful discussions during the meeting. The authors acknowledge financial support by the Austrian Science Fund (FWF) under projects P17772 and P15868.

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